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RUBBER REMOVAL FROM POROUS FRICTION COURSE(U) ILLINOIS 1/)

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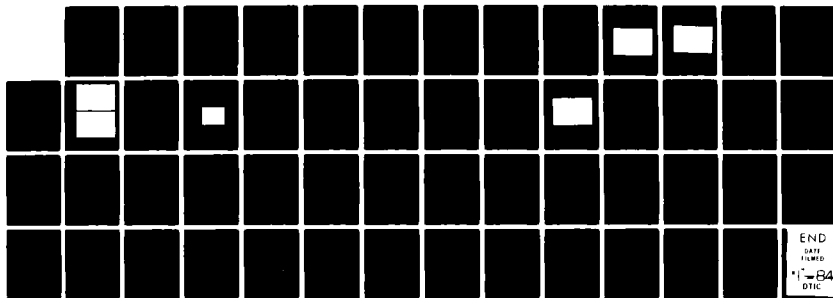
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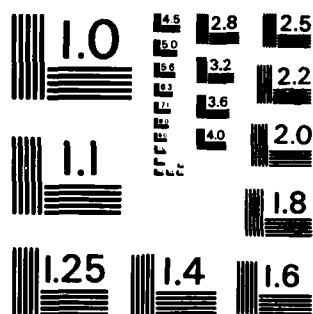
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Program Engineering &  
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Washington, D.C. 20591

# Rubber Removal from Porous Friction Course

AD-A135 276

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September 1983

Final Report

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16. Abstract <p>➤ Rubber buildup on runways is a serious problem because it reduces friction on the runway. Where a porous friction course has been placed to improve frictional and drainage characteristics the problem of rubber buildup becomes even more serious because friction and water drainage both are lost. This report examines seriousness of the occurrence of rubber buildup on porous friction courses and the methods which have been utilized to remove the buildup.</p> <p>Some innovative techniques have been used to remove rubber from a PFC, however, most could not be evaluated because the surfaces had been replaced or resurfaced. Of all techniques, high pressure water blasting was felt to present the most promise for efficient rubber removal.</p> <p>Discussions with contractors pointed out the difficulties in planning and controlling the high pressure removal technique. A simple analysis was conducted to illustrate the effect variations in the operating parameters had on the work being done by the water. Careful control of these parameters will be required for their use on PFC surfaces where the potential for damage is high.</p>			
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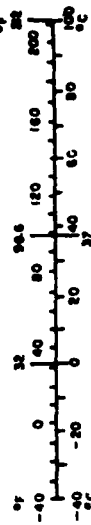
# METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures			
Symbol	When You Know	Multiply by	To Find
<b>LENGTH</b>			
in	inches	2.5	centimeters
ft	feet	30	centimeters
y	yards	0.9	meters
m	miles	1.6	kilometers
<b>AREA</b>			
sq in	square inches	6.5	square centimeters
sq ft	square feet	0.09	square meters
sq yd	square yards	0.8	square meters
sq mi	square miles	2.6	square kilometers
ac	acres	0.4	hectares
<b>MASS (weight)</b>			
g	grams	28	grams
lb	pounds	0.45	kilograms
oz	ounces	0.03	kilograms
<b>VOLUME</b>			
cc	cubic centimeters	1	milliliters
fl oz	fluid ounces	30	milliliters
qt	quarts	0.95	liters
gal	gallons	3.8	liters
cu ft	cubic feet	0.03	cubic meters
cu yd	cubic yards	0.76	cubic meters
<b>TEMPERATURE (celsius)</b>			
F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature
C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature

\* 1 in = 2.54 cm exactly. For other exact conversions and more detailed tables, see NIST Spec. Publ. 750, Units of Weight and Measure, Price \$2.25. NO Catalog No. (1) 10 704

60 mph = 52.1 knots (nautical miles per hour)  
60 mph = 88' / sec lg = 32.2' sec<sup>2</sup>

Approximate Conversions from Metric Measures			
Symbol	When You Know	Multiply by	To Find
<b>LENGTH</b>			
cm	centimeters	0.04	inches
m	meters	3.3	feet
km	kilometers	0.6	miles
<b>AREA</b>			
sq cm	square centimeters	0.16	square inches
sq m	square meters	1.2	square yards
sq km	square kilometers	0.4	square miles
ha	hectares (10,000 m <sup>2</sup> )	2.5	acres
<b>MASS (weight)</b>			
g	grams	0.005	ounces
kg	kilograms	2.2	pounds
tonne	tonnes (1000 kg)	1.1	short tons
<b>VOLUME</b>			
ml	milliliters	0.00	fluid ounces
l	liters	2.1	pints
m <sup>3</sup>	cubic meters	1.06	quarts
cu m	cubic meters	0.26	gallons
cu ft	cubic feet	36	cubic feet
cu yd	cubic yards	1.3	cubic yards
<b>TEMPERATURE (celsius)</b>			
C	Celsius temperature	5/9 (then add 32)	Fahrenheit temperature



1 mph = .87 knots  
1 knot = 1.15 mph

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## INTRODUCTION

Rubber buildup at the touchdown areas on airport runways results in a significant loss of skid resistance. The non-rotating tires on the fast moving aircraft scuff the surface of the stationary runway producing significant heat buildup which causes the rubber tire tread to soften and scuff off. This rubber is deposited on the pavement surface and after multiple landings, a concentration of built up partially melted rubber will accumulate. These many applications of rubber build up in the pores and grooves in the pavement surface effectively blocking them and reducing their ability to move water away from the surface, preventing the water from escaping from beneath the wheels of the aircraft. Hydroplaning will result when enough of these pores become clogged, reducing the skid resistance on the runway during a rain.

Various methods have been tried to remove this rubber buildup, all with varying success. These methods include:

1. Chemical softening or dissolution of the rubber.
2. Removal by blasting with high pressure water.
3. Removal by blasting with sand blasting equipment.
4. Removal by abrasion with steel shot.

Removal of rubber buildup with chemicals has fallen out of favor for large use because of environmental problems and the money and manpower requirements. The use of these chemicals on asphalt based pavements has not been satisfactory primarily because the chemicals also soften the asphalt cement in the surface layer which is detrimental to the long term performance of the pavement and leads to increased skid problems because

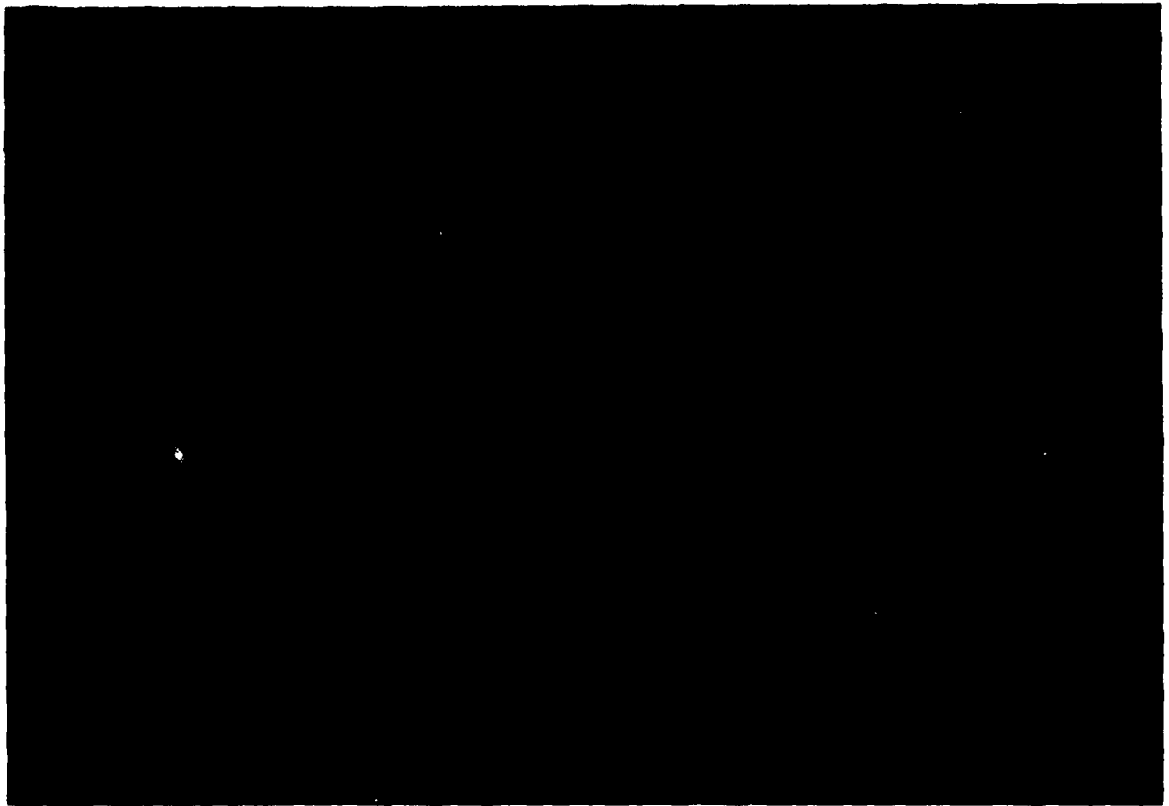
of the presence of the soft asphalt. Removal with sand blasting equipment is effective but it is costly and environmentally objectionable because of the silicosis problem produced by the silica sand dust. This requires the workers in the area to wear special clothing. Additionally, abrasive dust in the vicinity of jet aircraft is objectionable. Shot peening has been used to texture the surface of a concrete pavement prior to the application of a bonded concrete overlay, but it has generally been too expensive to use solely for rubber removal.

High pressure water blasting is a low priced effective procedure for removal of rubber deposits from Portland Cement Concrete ( PCC ) pavements. Water under pressures of up to 8000 psi is sprayed onto the surface to abrade the rubber off of the concrete. A typical unit is shown in Figure 1 operating on a PCC pavement. The removal of the rubber can be seen by comparing the right hand side of the photograph with the left hand side that has already been blasted. In normal operation this equipment will not harm the concrete surface. However, if the equipment is held stationary for a short length of time, the water jet will also abrade the concrete. This potential for damage has caused the greatest concern over the potential use of high pressure water blasting on porous friction courses ( PFC ).

Porous friction courses have been used on a number of airports to increase the skid resistance and reduce hydroplaning to the normal level expected for safe operation of high speed aircraft. Open graded asphalt mixes have proven to be an effective and economical method of temporarily improving the surface characteristics of the pavement. A highway PFC is shown in Figure 2. This mixture is designed to have a large number of



Figure 1. High Pressure Water Unit in Operation.



**Figure 2. A Porous Friction Course (PFC).**

permeable voids which allow the water falling on the pavement surface to penetrate into the asphalt layer and be carried out to the side of the pavement via internal drainage leaving the surface dry and reducing the potential for hydroplaning. The major concern is the potential for rubber buildup to occur on this surface, plugging the voids and eliminating the effectiveness of the PFC thereby reducing their economic advantage over other methods of skid improvement.

Because the texture of these PFC's is so open, the use of high pressure water blasting has been considered to be a risky operation. The high pressure water can easily tear up the thin PFC layer if it penetrates into the voids, or if the asphalt bonding is inadequate. It is known that Portland Cement Concrete can be eroded by the action of the water jet, and in at least one instance, at Stapleton International, a water jet has peeled a complete layer of asphalt concrete off of the underlying layer.

This project was developed to examine and document the extent of rubber buildup on PFC surfaces. Next, any techniques that had been tried were to be documented and explained for future consideration. Finally, a laboratory investigation of possible successful techniques was to be conducted if feasible. This study will indicate the extent of the rubber buildup problem and the techniques that have been tried to eliminate the problem. The remainder of this report will present the extent of the problem, the techniques that have been used successfully, operational problems with the successful techniques, and recommendations from contractors and airfield operators concerning the problem of rubber buildup on PFC surfaces and its removal.

## SURVEY RESULTS

Previous publications were consulted to determine where PFC surfaces had been placed (1,2).

The following airfields were identified as having had a PFC surface at one time in the past. The operators of all were contacted to determine their experience with the PFC surface:

1. Pease AFB, Portsmouth, NH
2. Hot Springs Airport, Hot Springs, VA
3. Nashville Metropolitan Airport, Nashville, TN
4. Naval Air Station, Dallas, TX
5. Kirtland AFB, Albuquerque, NM
6. Great Falls International Airport, Great Falls, MT
7. Stapleton International Airport, Denver, CO
8. Bartlesville Municipal Airport, Bartlesville, OK
9. Salt Lake City International Airport, Salt Lake City, UT
10. Greensboro High Point, Winston Salem Regional Airport, Greensboro, NC
11. Hill AFB, UT
12. Scott AFB, IL

## RESPONSES

### No Rubber Buildup.

Those airports serving general aviation without heavy aircraft reported no problem with rubber buildup. This coincides with the observations that fast landing speed and heavy aircraft are required to produce rubber buildup and that they must land at frequent intervals to produce a substantial buildup requiring removal procedures.

### Rubber Buildup

Rubber buildup on the PFC surface was reported at the following airfields:

Stapleton International Airport

Nashville Metropolitan Airport

Hill AFB

The responses about the seriousness of the buildup from each installation varied along with the techniques that were tried for removal. The comments from Hill AFB, which is shown in Figure 3 were to the effect that when the buildup problem became severe enough, those areas would be resurfaced.

Stapleton International Airport in Denver, Colorado had a severe rubber buildup that required treatment every six months. The severity was felt to be the result, primarily, of poor mix design.

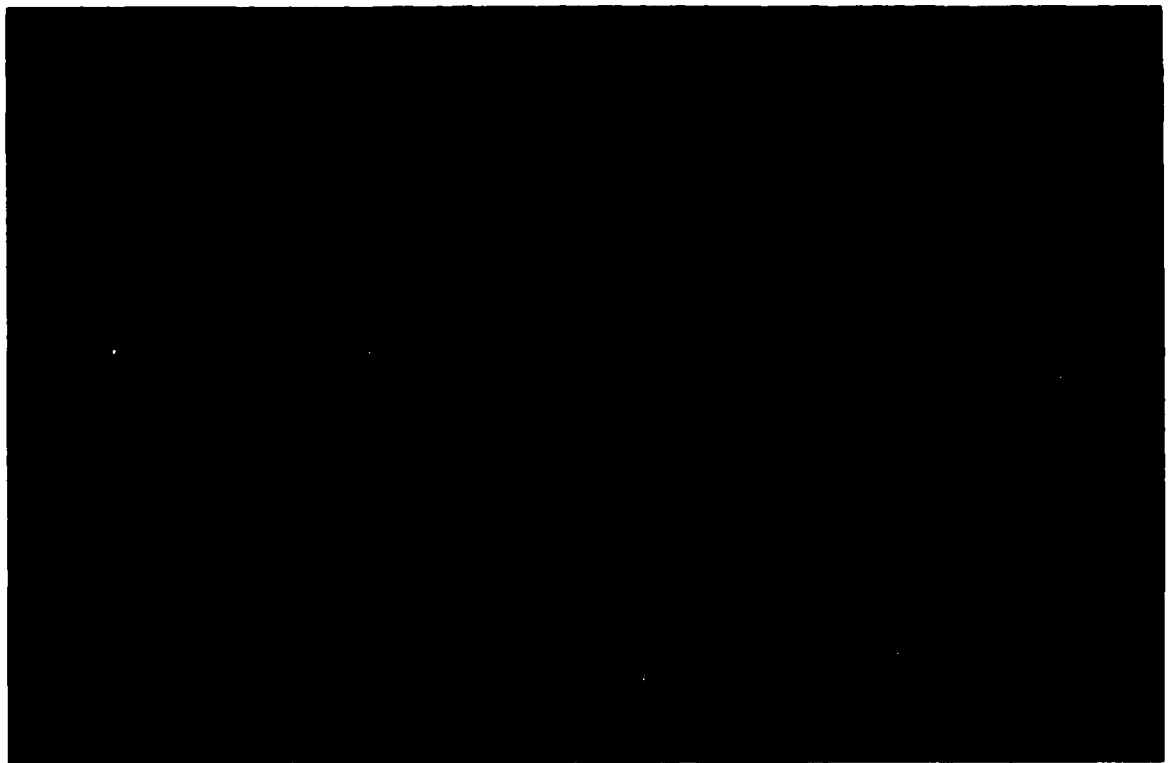
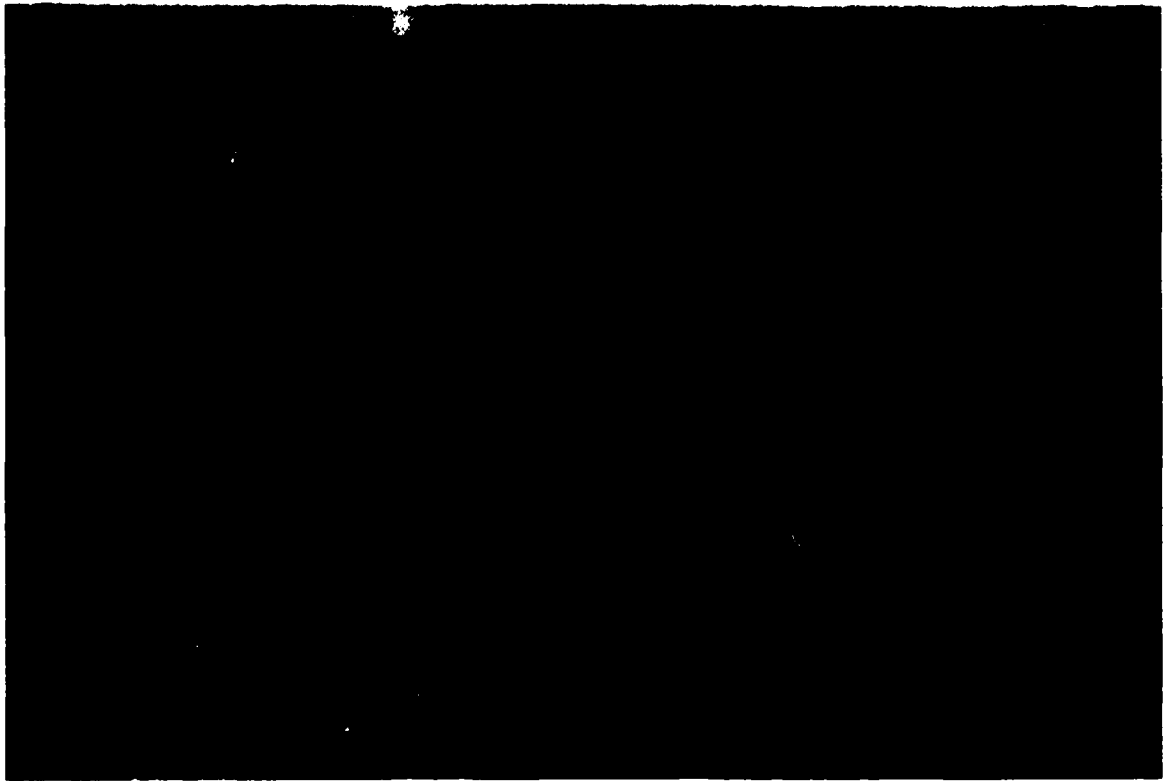


Figure 3. Photographs of Rubber Buildup at Hill AFB Utah, 1980.



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Nashville Metropolitan Airport had a minor rubber buildup that could not be attributed to a poor mix or other factor.

#### SOLUTIONS

Both the Stapleton and Nashville Airports had tried removal techniques to remove the rubber buildup. They could not be visited to evaluate the effectiveness of the rubber removal techniques used because both airfields had been reconstructed and overlaid shortly after the rubber removal was completed and prior to this study.

Stapleton Airport had been using high pressure water blasting every six months to remove their rubber buildup. The effect of this frequent cleaning on the structure of the PFC cannot be evaluated because of the reconstruction and concrete overlay placed in 1978. It is known that on several occasions, the high pressures used caused the PFC to peel away from the underlying surface. It is not known whether the mixture problems existing at Stapleton made any contribution to this PFC being more susceptible to damage from high pressure water blasting when compared to other PFC surfaces.

The contractor for the Nashville Metropolitan Airport utilized a novel technique to remove the rubber buildup from the PFC surface. A rotary sweeper brush was used to sweep the rubber off the PFC surface. The brush, similar to the one shown in Figure 4, was equipped with abrasive tipped bristles which abraded the rubber off the PFC surface and swept the loosened rubber and debris off the pavement area. The effectiveness of this procedure could not be evaluated because this airfield had been reconstructed with Portland cement concrete in 1975. However, the airport engineers from Nashville were favorably impressed



Figure 4. Pavement Sweeper Brush.

1

with the procedure and the results, stating that "... using abrasive tipped brushes was the best device we knew for cleaning the porous friction course. We believe this method was equal to high pressure water or chemical, all of which were tried at one time or another on this airport." The chemicals and high pressure water were never used on the PFC surface, however, and the abrasive sweeper was not used in subsequent years.

Chemicals were mentioned as having been tried at various times, but primarily on concrete pavements, and not on a regular basis due to cost and manpower necessities. Los Angeles International uses chemicals, primarily methyl chloride, entirely on concrete pavements, never on asphalt. This chemical is a powerful solvent for asphalt materials and could soften the asphalt concrete excessively. Milder chemicals with a detergent base were mentioned as possible alternatives, but no historical information could be obtained as to their use or effectiveness on asphaltic surfaces.

## OBSERVATIONS

Several airports that had experience with rubber removal from both concrete and PFC surfaces recommended several contractors who furnished information about their experiences in removing rubber buildup in a number of different situations. The amount of experience with PFC surfaces was limited, but the total information was quite useful in describing the overall problem of rubber buildup and removal.

### RUBBER BUILDUP

The rubber deposited during landing is not a stable compound, and it is different for different aircraft types. Light aircraft leave a different type deposit than the heavier aircraft which tend to leave heavier deposits. The initial deposits of rubber appear to undergo a change into a carbonlike deposit under continual traffic. This change in composition may result from the continual application of heat which causes a chemical change in the rubber. Additionally, the rubber in direct contact with the asphalt cement may undergo a chemical reaction with the asphalt compounds similar to what happens in the preparation of rubber-asphalt. If this occurs, and the rubber hardens under continual traffic, the removal of the rubber will also remove a portion of the asphalt cement. With repeated cleanings, this continual loss of asphalt cement could be detrimental to the integrity of the PFC through removal of the bonding provided by the asphalt cement. This would allow the aggregate to become loosened producing a safety hazard.

Infrequent landings do not increase the amount of rubber deposits appreciably, and the weathering appears to loosen the rubber making it easier to remove. Water on the pavement during landings may actually be beneficial and provide a scrubbing action for the rubber already deposited, preventing the new rubber from bonding with the old surface. In at least one instance this appears to have occurred in that continual presence of water on the flight deck simulator for an aircraft carrier produced steam during landings which prevented the rubber from bonding with the surface (3).

All of these factors interact to produce different types of rubber buildup. Each type of buildup will have different characteristics which will make it either easier or more difficult to remove.

#### RUBBER REMOVAL

It was continually stressed by both contractors and airport operators that the physical process of rubber removal has not been quantified into a science. They lack equipment that would be useful in evaluating a rubber deposit beforehand to determine whether it would be easy or difficult to remove at that particular time. A simple test that would allow them to set the pressure, height of spray bar, and forward speed of the vehicle would greatly simplify the process of removal. The toughness or tenacity of the rubber varies continually from one runway to another depending on traffic, climatic area of the airfield, and the type of surface. At present, the equipment must be adjusted on the go to obtain optimum operating conditions for removal of the rubber. The next removal project will likely require a completely different setup for the equipment.

High pressure water blasting can be used to remove any type or quantity of rubber deposit. The operation of the equipment, however, may require that some damage be done to the pavement to obtain the best removal. This damage has consisted of eroding the surface and ejection of the aggregate causing "popouts". Given the normal operating pressures in the range of 7000-8000 psi, the equipment must be closely controlled at all times to avoid concentrating the water jet over any one portion of the surface for any significant period of time. This is true for concrete surfaces, and even more so for asphaltic surfaces where the damage will be progressive as the jet exposes more void spaces as it penetrates into the layer of asphalt concrete.

The control of the equipment on a PFC surface is critical because damage to the PFC would be more detrimental to the mission than would damage to a portland cement concrete or asphalt concrete surface. Damage to the PFC would decrease drainage of the surface increasing the safety problem associated with hydroplaning, whereas damage to the concrete surface would be limited to localized erosion. If excessive pressures and inappropriate operating parameters are used, the PFC could be peeled from the underlying surface as has been noted previously. Extra care for a PFC surface may require more testing before production removal begins which could necessitate a higher unit cost for the removal.

High pressure water jet blasting has been used primarily for rubber removal on concrete runways, but there have been asphalt concrete areas used for turnaround of the pressure jet equipment. These areas have been exposed to the water blasting in the same manner as the concrete without damage. One such example is shown in Figure 5. This figure is for a

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Figure 5. Area of Asphaltic Concrete Subjected to High Pressure Water Blasting.



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dense graded asphalt concrete mix, but it indicates the ability of an asphaltic concrete surface to resist the high pressure water blasting.

An item of interest to both the contractor and the airfield authorities is the development of criteria to be used in evaluating the effectiveness of a removal operation. This is being studied by the Air Force in an attempt to develop a specification to be used as a comparison measure to evaluate the effectiveness of a removal procedure for contract compliance and payment determination. At present the evaluation is judgemental and is usually made from pictures taken before and after the removal process. This procedure does not provide a logical process for quantifying the effectiveness of the removal process.

There is still no process that effectively evaluates the influence of the rubber on frictional resistance before removal. Any contract compliance program will require a before and after evaluation process to determine the effectiveness of the removal process. Additionally, levels of acceptable friction, or whatever parameter is chosen to determine compliance, will need to be selected and communicated to the contractor before he begins work.

Some work is being conducted into a self-cleaning mixture design for a PFC surface by the Air Force. This work has the potential to make this discussion moot. This self-cleaning action has been noticed on some PFC surfaces constructed with aggregate that produce a conchoidal fracture surface. These aggregate particles tend to slice the rubber more than rub it off of the tire, and the curved fracture surfaces let the rubber peel away very easily.

## IMPLICATIONS

High pressure water blasting is considered the most effective method for rubber removal. Its use on PFC surfaces requires further investigation, as not many PFC surfaces have been in service with a rubber buildup. Chemicals have no use at present on asphalt surfaces. The use of the abrasive tipped rotary sweeper brush may be a promising technique for further consideration.

The real questions of concern center on the ability to determine the effectiveness of any removal technique because the makeup of the rubber is so variable. To assist in this determination and to provide the engineer with an indication of the operating characteristics of a typical high pressure water blasting operation, a parametric study was conducted and is presented in Appendix B. This simplified analysis was designed to indicate the variability produced in the removal procedure when the operating parameters are changed slightly. This study was not designed to provide an absolute indication of the work required to remove a quantity of rubber buildup. The sensitivity analysis presented in the appendix illustrates the control that must be exerted in the removal procedure to ensure repeatable results.

## CONCLUSIONS

The problem of rubber buildup can be very serious when it occurs. The survey of airfields indicated that in the limited number of occurrences the rubber buildup had been dealt with successfully. Unfortunately none of these surfaces are in existence today to allow a thorough study of the effectiveness of the procedures. Of the various procedures that have been successfully used on PFC surfaces, the high pressure water blasting appears to be the most adaptable to differing situations that may arise on a PFC type surface.

Because of the variation in the rubber deposits produced by surface type, climate, and traffic level on the different runway surfaces it is impossible to know beforehand what operating characteristics will be required for adequate rubber removal. The use of the high pressure equipment must be altered for every runway. This trial and error technique will not damage concrete pavements but could be very detrimental on a PFC surface. Work should be done that attempts to identify the nature of the rubber deposit (all pavement types) through a sampling program from airfields in all regions of the country and a suitable chemical and visual (electron microscope) analysis. A procedure to evaluate the effectiveness or completeness of the rubber removal must be developed. This procedure should ideally be related to a measure of the physical condition of the pavement and not just a visual survey. Equipment should be examined more thoroughly on actual rubber removal contracts and the operating characteristics recorded, varied, and compared with the measure of effectiveness developed. A more thorough researching of the complicated constitutive equations involved in high pressure

spraying should be done to more accurately define the ability of different equipment to remove rubber and provide a comparison with the actual efficiency observed on the runways.

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1. White, I. D., "Field Performance of Porous Friction Surface Course", Report No. FAA-RD-74-38, 67 pp., April, 1976.
2. Clark, J. I. and J. E. Watson, "Maintenance of Porous Friction Surfaces", Special Study, Air Force Engineering and Services Center, Tyndall Air Force Base, Florida, 140 pp., June, 1980.
3. Private Communication with Rubber Removal Contractor.

APPENDIX A

ANNOTATED BIBLIOGRAPHY

1. Effectiveness, Skid Resistance, and Antihydroplaning Potential of Porous Friction Courses.

Author: Duggan, L. F.

Transportation Research Board Special Report #175,  
pp. 64-67; 1978

The Airport Operators International survey has provided an operational assessment of the effectiveness of the porous friction course as an alternative to grooving to reduce hydroplaning at airport facilities. Airport operators that have applied porous friction courses are pleased with their performances, both as to friction characteristics and wearability. The Federal Aviation Administration has evaluated these courses for airport pavements and presented data on their design, construction, and performance. This technical evaluation essentially supports the consensus of the operational survey that performance has been good. On the assumption that asphalt concrete grooving and porous friction courses are equally effective, airport operators are encouraged to explore the cost of each in their geographic areas to determine which is less costly. If the aggregates necessary to meet specification requirements must be hauled in, grooving may be the better choice. In the airport operators' opinion, design specifications and acceptable cleaning methods have not been fully explored. The success of porous friction courses that use larger size aggregates with a more open textured course suggests that design may be the key with a rotating spray bar for removing rudder deposits seems to have potential.

2. Evaluation of High Pressure Water Blast with Rotating Spray Bar for Removing Paint and Rubber Deposits from Airport Runways, and Review of Slipperiness Problems Created by Rubber Contamination.

Authors: Home, W. B. and Griswold, G. D.

National Aeronautics and Space Administration Report No:  
NASA-TM-X-72797; Nov. 1975, 60 p.

A high pressure water blast with rotating spray bar treatment for removing paint and rubber deposits from airport runways is studied. The results of the evaluation suggest that the treatment is very effective in removing above surface paint and rubber deposits to the point that pavement skid resistance is restored to trafficked but uncontaminated runway surface skid resistance levels. Aircraft operating problems created by runway slipperiness are reviewed along with an assessment of the contributions that pavement surface treatments, surface weathering, traffic polishing, and rubber deposits make in creating or alleviating runway slipperiness. The results suggest that conventional surface treatments for both portland cement and asphaltic concrete runways are extremely vulnerable to rubber deposit accretions which can produce runway slipperiness conditions for aircraft operations as or more slippery than many snow and ice-covered runway conditions. Pavement grooving surface treatments are shown to be the least vulnerable to rubber deposits accretion and traffic polishing of the surface treatments examined.



3. High Pressure Water Removes Rubber from Runways.  
Public Works, March 1971, Vol. 102, No. 3, pp. 82-83.

High pressure water was used to remove a five-year accumulation of rubber deposited by heavy jet aircraft as they land on the principal runway at the greater Buffalo international airport. While water alone, at 4,000 to 6,000 psi, was very effective in removing the rubber, the rate of production was slow. With silica sand induced into the stream, the rate of cleaning was increased at least 3-fold. However, the sand causes rapid wear of the small orifices in the tungsten carbide nozzles, requiring frequent expensive and time-consuming replacements. As a result, a limited amount of a solvent, magnus no. 775, was spread over the rubber-strained concrete and allowed to work for 20 minutes before the high pressure water was applied. At least 95% of the rubber was removed, with no adverse effects. Rubber was removed, with no adverse effects.

4. Maintaining Airport Pavement.  
APWA Reporter, Vol. 42, No. 7, July 1975, pp. 12-14.

A combination of increased loads and traffic can cause rapid airport pavement deterioration requiring a dynamic and continually updated maintenance program. Steps for the establishment of a maintenance program are outlined and examples of several types of problems encountered are given. After a pavement evaluation is made and an inspection program is initiated, historical records can be maintained indicating the scope of repairs necessary. Recommended repair for bituminous pavement includes a remedy for pavement failure which occurs in areas subjected continuously to jet fuel spillage. After a period of use, an accumulation of tire rubber, oil, and carbon in the form of jet soot builds up on the runway. Rubber removal with chemicals has been used, but runway grooving has been found to be the most effective means of eliminating factors which reduce the tire-ground friction forces.

5. The Potential of Porous Friction Courses  
Airport Management Journal, Vol. 2, No. 2, April 1977, pp. 6-9.

A survey conducted by the Airport Operators Council International (AOCI) to gather data on grooved and porous friction course (PFC) treatment of runway surface is described. The AOCI survey has served to provide an operational assessment by airport operators of the effectiveness of PFC as an alternative to grooving to reduce hydroplaning at airport facilities. Based on average cost data received, grooving PCC was the most expensive technique and grooving of asphalt the least expensive. PFC costs were found to be between the two. The most commonly used groove configuration in the nation was one quarter inch by one-quarter inch by one and one-half inch. That configuration on PCC cost 50% more than the same configuration on asphaltic concrete. It was found that rubber deposits and other contaminants did not build up as quickly on grooved or PFC surfaces. Those airport authorities not treating their runways reported that it was either not needed, inadequate information, or too costly. The only poor performance has been reported in Nashville, Tenn. and the reason is not readily explained, although the performance of limestone aggregate in PFC has not been clarified. The report concludes that by following the design method, quality control procedures, and good construction practices recommended, PFC pavements can be constructed with a higher degree of confidence. The success of PFC in the Rocky Mountain Region using the larger-size aggregate with a more open-textured course suggests that design may be the key to rubber build up. High-pressure water blast with a rotating spray bar for removing rubber deposits also seems to have some potential.

6. Removal of Rubber Deposits on Runways

Investigators: Sandhawalia, P. S., Kulshushtha, H. K.

During high speed braking, the rubber from aircraft types gets worn off and deposited on runway surface. This deposited rubber smooths the surface texture reducing braking coefficient leading to the possibility of loss of control and overshooting during landings. This paper reviews experiments designed to examine the suitability of either removing the rubber-bitumen scum from surface of runways or to provide a friction course.

7. Runway Cleaner  
Public Works, Vol. 103, No. 6, June 1972, p. 153

This is a non-polluting chemical compound for airport runway cleaning and rubber removal. It is applied to the pavement, then rinsed away, leaving a film-free surface. The compound has passed corrosion tests on all common materials used in aircraft and runway structures. When used in accordance with instructions, it is 96.8 percent biodegradable.

8. Runway Friction Changes due to High-Pressure Water-Jet Cleaning Operations, Houston Intercontinental Airport, Houston, TX  
Authors: Hiering, W. A.; Grisel, CR  
National Aviation Facilities Experiment Center; Report No.:

The subject effort was to evaluate a new method of removing rubber from airport runways in terms of its effect on runway surface friction. This rubber removal method consisted of jetting water at high velocities to remove the rubber deposits from the surface. The results of the tests indicated that the contractor's equipment and method of operation removed all the above-the-surface rubber deposits, did not visibly damage the runway surface, and increased friction in the rubber-laden aircraft touchdown areas.

9. Runway Surface Friction Changes due to High-Pressure Water-Jet Rubber Removal, Charleston Airport, Charleston, SC  
National Aviation Facilities Experiment Center; Report No. 21p  
FAA-NA-75-4

The study determined if the utilization of a new method of removing rubber deposits from an airport runway would change the surface friction of that runway. The method consisted of jetting water at high velocity to hydraulically remove the rubber from the surface. The results of these tests indicated that the equipment used by the runway-cleaning contractor did not damage the runway surface; however, it did not appreciably change the friction characteristics, probably due to the incomplete removal of all rubber deposits.

10. Status of Runway Slipperiness Research

Author: Horne, WB

Transportation Research Record No. 624, pp. 95-121; 1976

Runway slipperiness research performed in the United States and Europe since 1968 has been reviewed. This review suggests the following benefits to the aviation community: Better understanding of the hydroplaning phenomena; a method for predicting aircraft tire performance on wet runways from a ground-vehicle braking test; runway rubber deposits identified as a serious threat to aircraft operational safety; methods developed for removing rubber deposits and restoring runway traction to uncontaminated surface levels; and developed antihydroplaning runway surfaces, such as pavement grooving and porous friction course, which considerably reduce the possibility of encountering aircraft hydroplaning during landings in rainstorms.



11. Summary of Runway Friction Changes due to High-Pressure Water-Jet Cleaning Operation at Four Airports  
Author: Grisel, Charles  
National Aviation Facilities Experiment Center; Report No.: FAA-NA-76-66

The subject effort evaluated a new method of removing rubber from concrete runways in terms of its effect on runway surface friction. This rubber removal method consisted of jetting water at high velocities to remove the rubber deposits from the surface. The results of the tests indicate that commercial equipment and procedures can be used to remove all the above-the-surface rubber deposits, do not visible damage the surface, and increase wet runway surface friction in the rubber-laden aircraft touchdown areas.

12. Transport Canada Runway Coefficient of Friction Operational Maintenance Program

Author: Levitsky, WV

Transportation Research Board No. 622; pp. 100-104, 1976

The objective of this program is to ensure the provision of safe airport runway operating conditions for efficient air transportation in Canada. This is being accomplished by the establishment of standards covering minimum coefficient of friction for runways, procedures and instruments of measurement and by periodical assessment of runway surface conditions. These standards take into account the runway length, runway elevation, wind and the type and weight of scheduled aircraft. The instruments used in measuring runway coefficient of friction were tested by the International Civil Aviation Organization on selected pavements, representing most typical runway conditions, and have useable correlation with aircraft performance for certain aircraft type. During winter months, the runway coefficient of friction is measured and reported on a routine basis as part of snow removal and ice control using James Brake and Tapley Meter Decelerometers at designated airports. Although no comparable program of operational measurement and reporting during rain storms exists in the summer, an ongoing evaluation program of runway calibration under wet conditions is in effect. The Skiddometer BV11-2, a continuous measuring and recording instrument, is used to measure the runway coefficient of friction in conjunction with a self-watering system. The frequency of runway evaluations is based upon the annual number of scheduled aircraft movements and the class of aircraft. A procedure is being established by which air carriers will be notified of runways which lie near the borderline of the minimum established coefficient of friction value. Provision is made to initiate corrective action for

12. Continued

those runways whose coefficient of friction under standard wet conditions, falls below the minimum safe values. Remedial measures to restore runway coefficient of friction are dictated by the causes of slipperiness such as rubber contamination, polishing of the surface texture or insufficient surface draining of water. Effective techniques to implement corrective action range from removal of rubber deposits by high pressure water or lateral corrugation, retexturing polished surfaces by impact hammering or grooving to improve lateral drainage of water.

## APPENDIX B

### High Pressure Water Blasting

During the discussion with airport personnel and contractors, both groups expressed concern about the lack of knowledge about the control required in a high pressure water blasting operation for rubber removal to ensure consistent removal. A limited study of manufacturer's literature and the physical mechanics of the spray system was performed to develop some simplified data that could be used to show how critical the control of parameters was to the effectiveness of the rubber removal. The parameters identified include the following:

1. Water pressure, psi
2. Flow rate, gpm or cfs
3. Orifice size, inches
4. Fan spray angle, degrees
5. Height of spray nozzle above surface, inches
6. Forward speed of the vehicle.

Variations in these parameters cause the amount of water striking the surface, in a unit of time, to vary. The amount of water per unit time relates directly to the amount of work being done on the surface, which should be an indication of the amount of rubber being removed. When more work is done in an area of surface, more rubber should be removed. On a given pavement/rubber combination this will be a direct relationship, however, because this combination varies widely from one airfield to another, the effectiveness cannot be directly translated from what is observed on one pavement to what should be expected on another.

The developments in this appendix are meant to be used as indicators which show how the quantity of work being done on the surface changes as the operational parameters change. The comparisons of the work quantity at various selected levels of the operating parameters will show how closely the operating parameters must be controlled to prevent excessive variation in the work being done on the pavement surface. Whether the work value presented as standard actually does an acceptable job of rubber removal cannot be determined except through field examinations. The purpose here is to provide indications of where variability, on one project, can occur to cause an unacceptable project.

#### DEVELOPMENT

A spray nozzle and the water spray fan are shown in Figure B-1. The idealized spray fan is shown with the actual coverage superimposed. The actual coverage is greater than the theoretical coverage only for small distances above the pavement surface. Figure B-2 illustrates the difference for a nozzle commonly used in rubber removal. The spray fan is much wider than the theoretical prediction for the small heights commonly used in rubber removal projects. The thickness of the spray fan increases with height also. This increase is shown in Figure B-3 for the typical nozzle. With the change in the width and thickness as the height of the spray fan increases, the force per unit area decreases, which decreases the work being done. The cross sectional area can be calculated as follows:

$$\text{Area} = A = a + 2 \left( \frac{h}{\tan \frac{\alpha}{2}} \right) (0.0192h + 0.0947)$$

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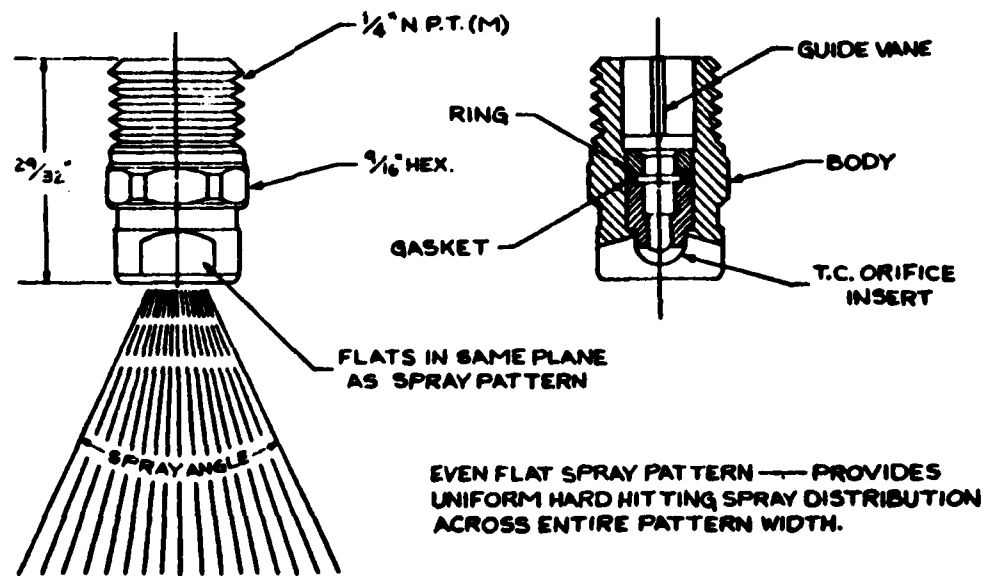
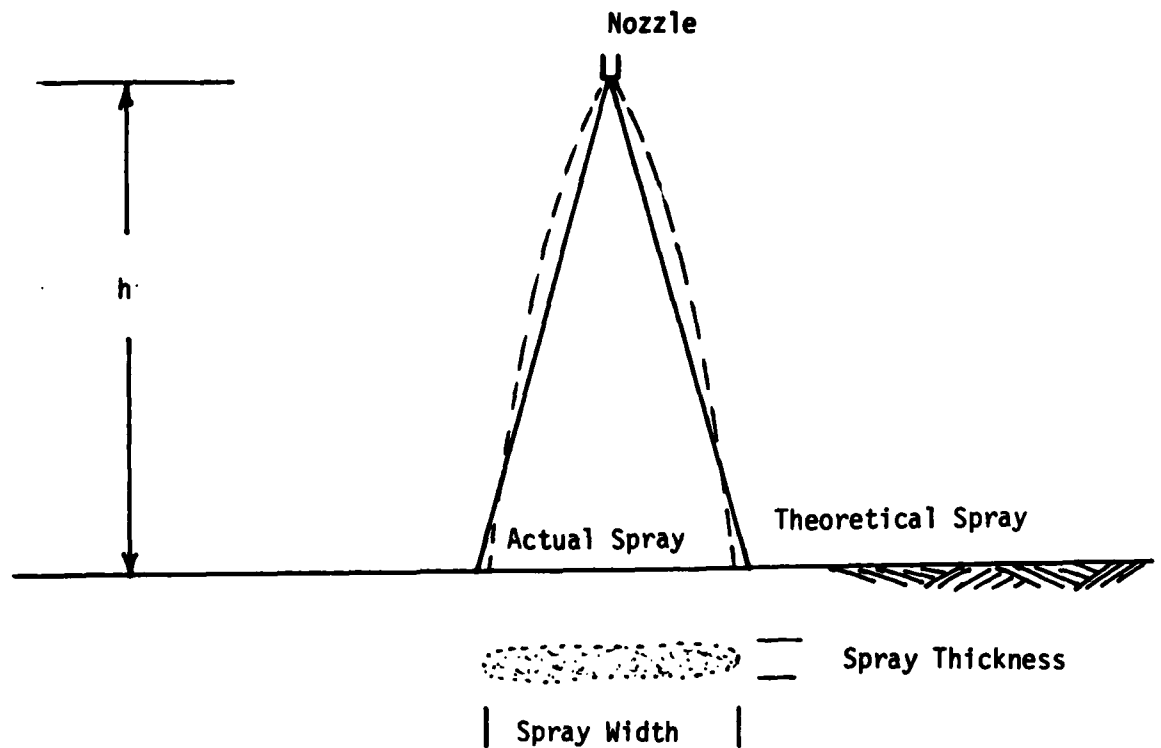


Figure B-1. Spray Nozzle and Spray Fan Configuration, from Spraying Systems Co.

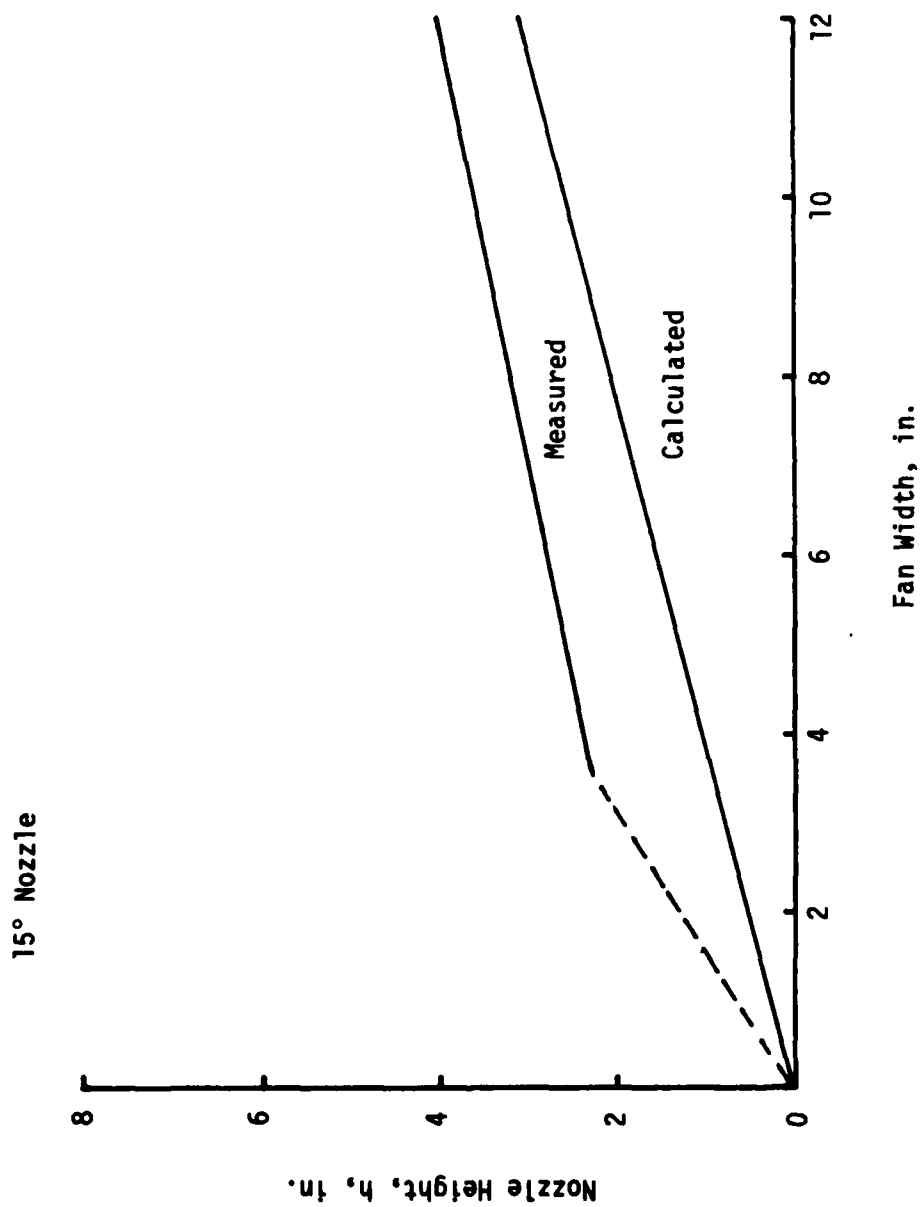


Figure B-2. Variation in Fan Width as a Function of Spray Bar Height, Comparing Actual to Theoretical.



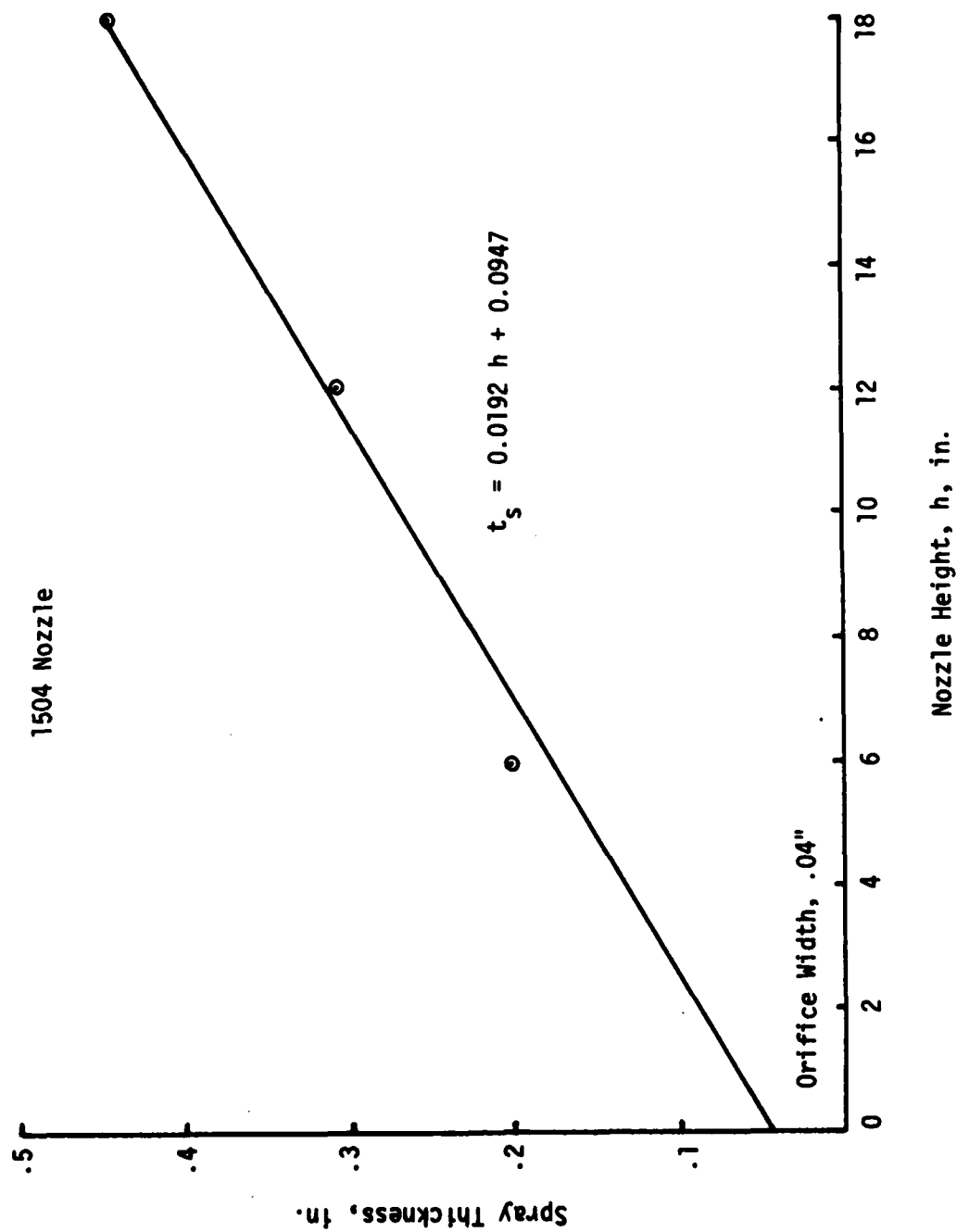


Figure B-3. Variation in Fan Spray Thickness as a Function of Spray Bar Height.

where:

a= opening diameter, inches

= spray angle, degrees

h= spray height, inches

The jet of water delivers a constant mass at any height. This quantity of water is determined by the orifice size, a, the pressure, and the discharge rate. The operational characteristics of high pressure water pumps in use today are such that the operating pressure and discharge rate are fixed for a particular application by internal equipment changes. The number of spray nozzles in the system is changed so that the rated output of the total nozzles used corresponds to the output of the pump at the selected operating configuration. The operating characteristics for the nozzle demonstrated here is shown in Figure B-4. The flow rate increases as the logarithm of the pressure. The equation for this nozzle is:

$$q = 2.0958(\text{LOG } P) - 4.1998$$

where:

q= flow rate, gallons per minute

P= Pressure, psi

This relationship can be used to calculate the momentum and force of the mass impinging on the surface. All calculations are per unit area. This can be termed the energy density.

$$\text{E.D.} = (mV^2)/(2A)$$

where:

E.D.= energy density

m= mass = qt/g

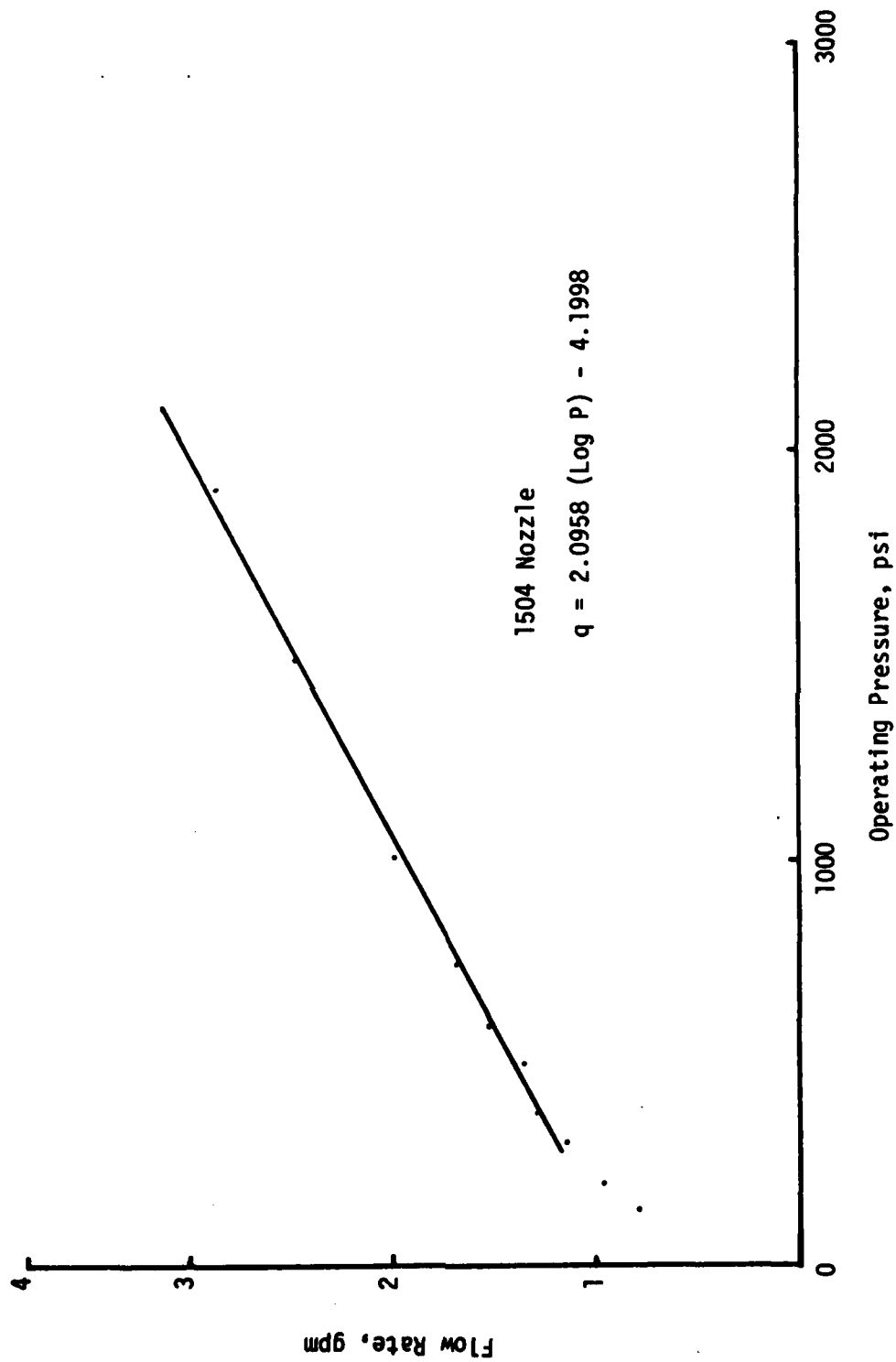


Figure B-4. Flow-Pressure Relationships for Nozzle Type 1504. Indicating Typical Operating Characteristics.

V= velocity, ft/sec =  $q/A$

A= area of spray, ft

$\rho$ = density, pcf

q= discharge rate, cfs

t= time the spray remains over one point =  $t/v$

$t_s$ = thickness of the spray

v= velocity of the vehicle fps

This reduces to  $m=1.95 \ q \left(\frac{t_s}{v}\right)^2$  .

Which after appropriate substitutions produces the equation:

$$E.D. = \frac{1.95 \ q t_s \ q^2}{2vA \ A^2} = \frac{1.95 \ q^3 t_s}{2v \ A^3}$$

where the variables are as previously defined.

The graphs in Figure B-5 through B-7 illustrate the variation produced in the energy density with variability in the operating parameters. Typical ranges for these operating parameters have been indicated for comparison purposes only.

It can be clearly seen that variation in the pressure is not as critical to the effectiveness of the removal procedure as the variation in vehicle speed or the height of the spray bar. This indicates where care must be used in the high pressure removal process.

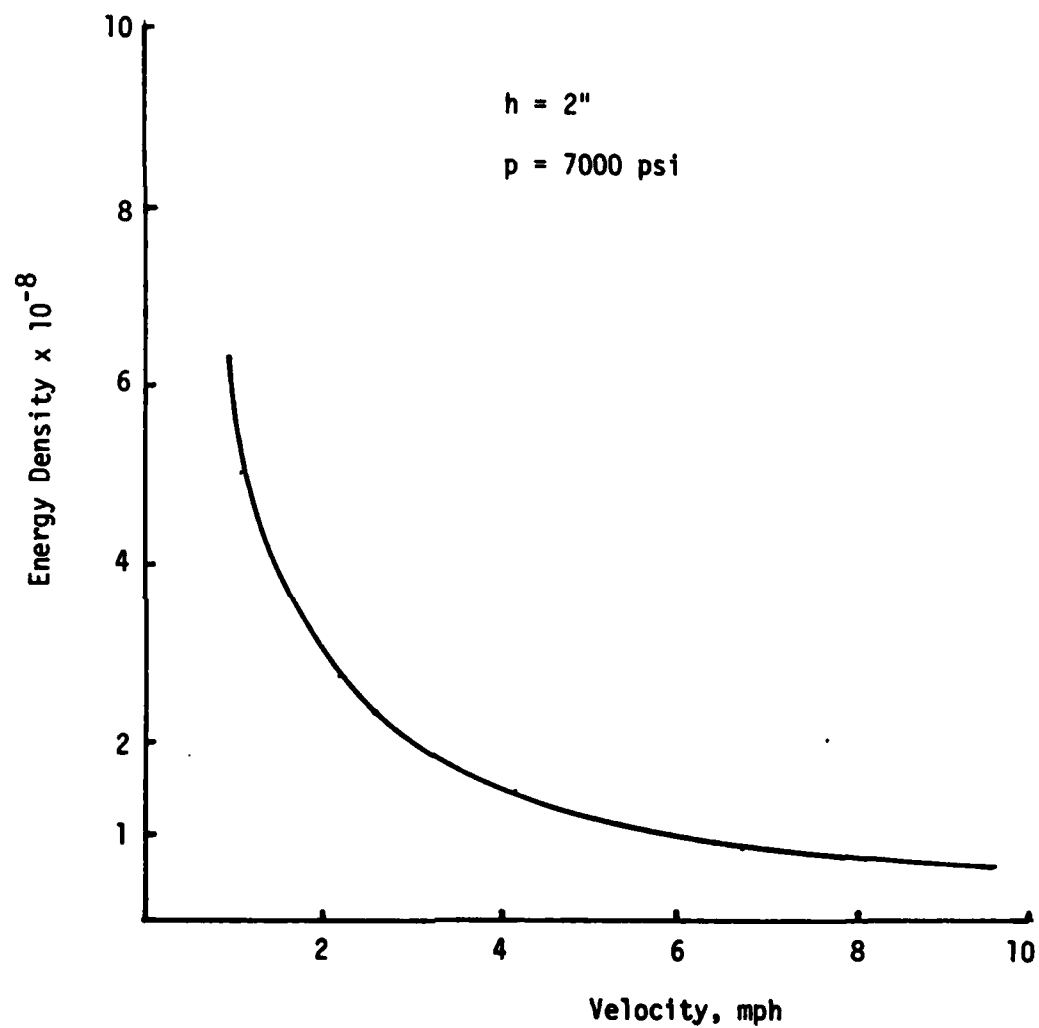


Figure B-5. Influence of Vehicle Speed on the Work Done on the Surface.

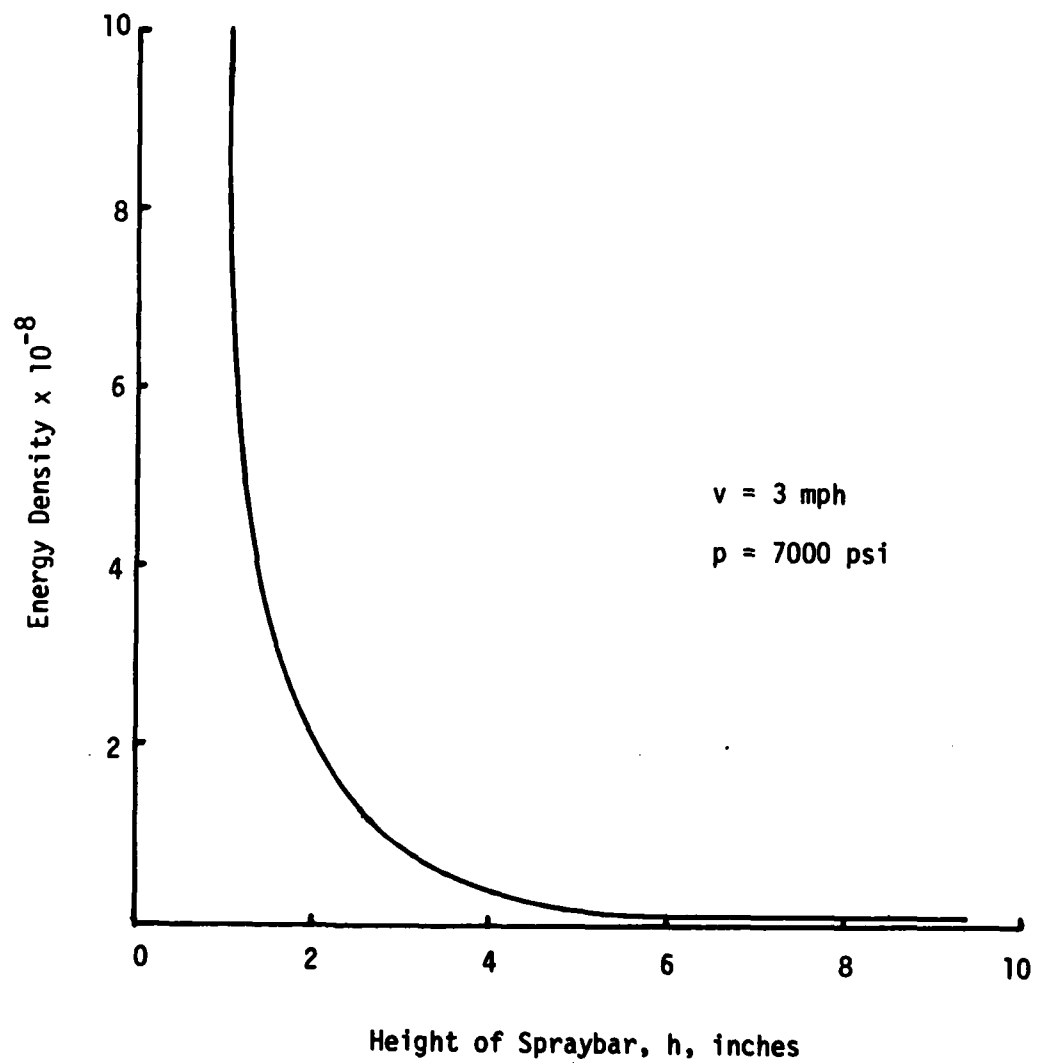


Figure B-6. Influence of Spraybar Height on the Work Done on the Surface.

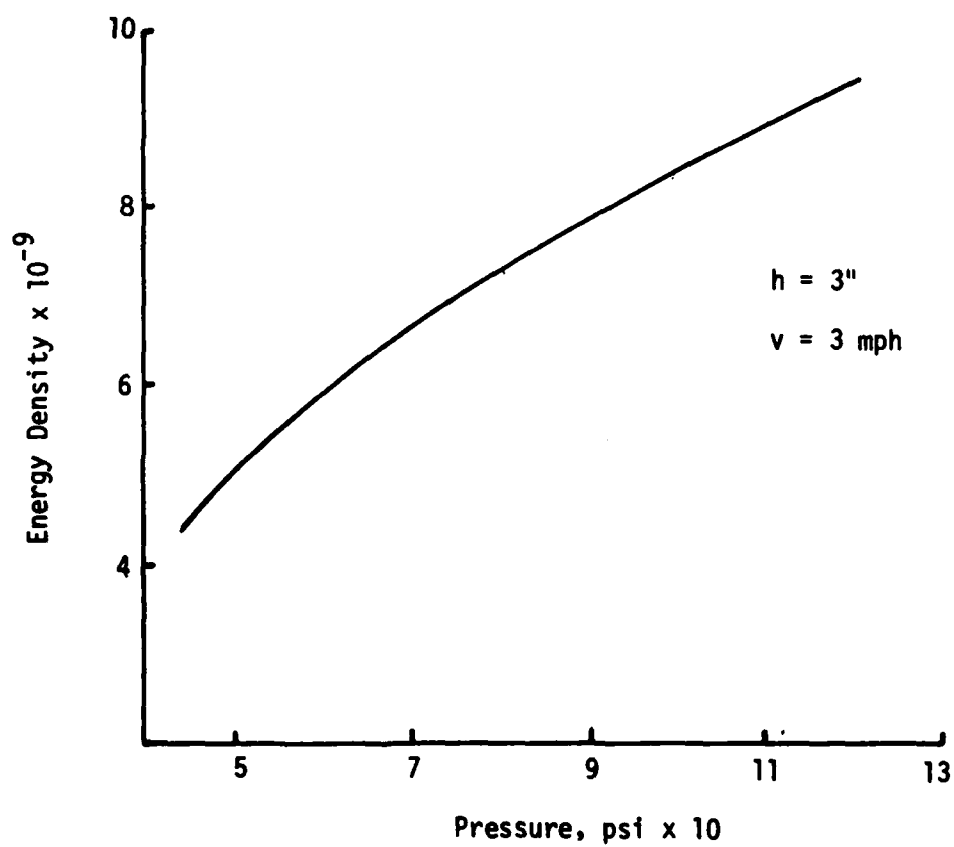


Figure B-7. Influence of Pressure on the Work Done on the Surface.

